INVERTEBRATES AS ECONOMIC RESOURCES

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The application of evolutionary biology and related disciplines (ecology, natural history, systematics and natural products chemistry) to the search for new invertebrate resources is yielding an array of novel products from a variety of unexpected sources. While this application is not new, (for example, it has been the basic paradigm in the search for biological control agents), it is under-utilised and hence undervalued. Recent examples with proven or potential commercial applications include: antibiotics and termiticides from ants, high tensile fibres from spiders, venoms from mites, spiders and scorpions for pesticide development and medicine, new adhesives from barnacles and velvet worms, novel construction materials from deep sea molluscs and a wide variety of invertebrates suitable for pharmaceuticals and biomonitoring of water and soils. These and many other examples demonstrate that (i) the deductive power of evolutionary biology and its related disciplines is of commercial importance, (ii) invertebrates in general are proving to be vital biological resources likely to yield many new products and services, and, therefore, (iii) in addition to the ecological and ethical reasons for the conservation of invertebrates, economic considerations independently highlight the folly of failing to make invertebrates the focus of major conservation efforts.

☐*Invertebrates, resources, economics, evolutionary biology.*

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That is the one point I think all evolutionary biologists are agreed upon, that it is virtually impossible to do a better job than an organism is doing in its own environment (Lewontin, 1967). This quotation begins a re-examination of the concept of the application of evolutionary biology to the discovery of useful biological resources. Having reviewed its current use I will then apply it to the invertebrates.

Human beings have taken advantage of adaptations in a general way for thousands of years whenever animals and plants have been used or harvested for many different kinds of products including food, fibre, medicines and building materials. However, more recently, the search for adaptations has been far more explicit and systematic. There are two areas in particular where this is true: biological control and biological monitoring (DeBach & Rosen, 1991; Holdway, 1991). The procedures required to find a biological control agent are very familiar. An enemy of the pest in question is sought, usually in the home range of the pest. The enemy may be a parasite, parasitoid, fungus, bacterium or a gene, for example, for resistance. The main objects of the search, however, are the particular adaptations that enable the control agent to attack and destroy the pest species.

The search is usually explicitly for an adaptation or a set of them. For example, a lepidopteran larva pest may be controlled by a parasitoid wasp. The biologists involved then seek out wasp species that exhibit the appropriate life-history and behavioural adaptations. The actual search usually has a hierarchical structure, first identifying the correct geographic area, then the habitat, vegetation type, and finally the individual plant species and even particular tissues such as the flowers or leaves. A similar kind of protocol has been occurring in the search for organisms that may serve as biological monitors, in particular, in ecotoxicological studies. Here, the demand is for continuous, accurate, cost-effective sampling across broad areas. In some cases, the search for the appropriate adaptations has been articulated in evolutionary terms: which organisms are adapted to sampling media or substrates continuously as part of their normal metabolism and behaviour? Many organisms spring to mind: in aquatic and marine environments a wide range of invertebrate, larval filter-feeders, many kinds of molluscs, protozoans and fish. There is a lot of research in Australia, and elsewhere in the world, to find the species with the most appropriate adaptations for particular monitoring tasks and a great variety of invertebrates have been proposed - crustacea, bivalves, echinoderms, polychaetes and oligochaete worms, and some species are already sacrificing their lives to the cause (Holdway, 1991; Anon, 1989). Individuals are taken to the lab and either the whole organism or selected tissues used for analysis.

At this point it is appropriate to reflect that because of the social and commercial demand for biological control and monitoring agents, an enormous range of organisms, notably invertebrates, are either potential or proven biological resources. This may appear obvious to some biologists but it is not at all obvious to most people. In fact, the idea is usually regarded as positively bizarre. Yet, crazy as it may seem, organisms as humble and diverse as parasitoid wasps, predatory beetles, invertebrate filter-feeders, and polychaete and oligochaete worms are positively and profitably biological resources. Therefore, no matter how small or obscure, pretty or ugly, these organisms must be counted along with trees, soils and fish stocks as resources requiring conservation and careful management.

AN EXAMPLE OF THE EVOLUTIONARY APPROACH

The evolutionary paradigm has yielded many biological resources but its potential is such that we have not yet seen much more than the tip of the iceberg especially for the invertebrates. There is no mystery here. What the biological control and biomonitoring researchers have asked, either explicitly or implicitly is: 'Where would we expect the appropriate adaptations to have evolved?'

This is an immensely powerful question. My own research is an on-going example. The increasing levels of antibiotic resistance among human pathogens is reaching truly frightening proportions and pharmaceutical companies are searching for completely new kinds of molecules. We started by asking the question: 'Where would we expect antibiotics to have evolved?' There is one familiar answer that the drug companies know about: among soil fungi competing with each other for resources by diffusing chemicals toxic to other microorganisms.

However, there are many other answers prompted by this question. One of our answers proceeds as follows: Antibiotics may be expected to evolve: (i) wherever the risk of disease by contagion is greatest which is likely to be (ii) in aggregations of animals such as breeding grounds, feeding flocks, and over-wintering aggregations, or perhaps most likely (iii) wherever animals live together permanently, (iv) in large numbers, such as insect societies, especially those that are (v) highly organised and (vi) where the young are kept together. This reasoning points towards the insect societies including the ants. Research has shown that the bull ant *Myrmecia gulosa* possesses a pair of glands, the metapleural glands, that secrete materials with antibiotic properties. Recent assays of both crude secretions and selected fractions have revealed interesting patterns of antimicrobial activity (Veal et al., 1992; Beattie et al., 1986). The molecules responsible for the antibiotic activity are potent and appear to be unusual. The research has been supported by the Australian Government and by a multinational harmaceutical company.

The importance of this example is to show that once the basic evolutionary question was posed, a hierarchy of questions and deductions based on natural history knowledge was possible and this process identified a target group of organisms. Evolutionary biology identified a previously unsuspected source of antibiotic substances.

The great advantage of evolutionary biology and its associated disciplines — natural history, ecology, genetics, systematics and natural products chemistry — is that it provides an organised structure and vast database that opens up entirely new horizons together with a rationale that enables us to focus on that habitat, group or family of organisms, behaviours, interactions, tissues or products most likely to merit commercial exploration. This should increase the efficiency with which potential new products are located. In the words of the old axiom: 'The secret of finding something is knowing where to look'.

In the laboratory, the process has been taken further by seeking other groups with life- history traits that suggest the evolution of antibiotics: we have collected metapleural secretions from central American leaf-cutting ants that cultivate a single species of fungus for food, actively suppressing large numbers of bacteria and fungal species that otherwise contaminate their cultures. Also, we have selected termite species using the following criteria that suggest the likelihood of the presence of antibiotics: large colony size, nest structures that aggregate individuals rather than dispersing them, distinct nurseries for juveniles, presence of food stores and long-lived adults. Our first data demonstrate that there is clear regulation of the microbiota in termite nests.

INVERTEBRATES AND THE EVOLUTIONARY PARADIGM

There are many more examples where the evolutionary paradigm might be used in the search for antibiotics and other bioactive materials. However, I would like to illustrate how broad the application may be by the use of two very different examples: biominerals and spider silk.

The first area of interest is structural engineering. In one case the question asked was: 'Where would you expect the evolution of materials that were both structurally rigid yet with some degree of flexibility?' Careful reasoning then pointed to the shells of certain deep-sea molluscs and their ultrastructure provided the stimulus for new man-made materials now used in car parts and new types of concrete (Webb et al., 1991).

In a very different area, the ceramics industry has been analysing mollusc shells and radulas for the control of crystallisation processes, especially where there are specific and complex additives that must be incorporated into the final product. The radula, for example, may be hardened with iron oxides that are incorporated into the final structure to make an extremely hard surface. Engineers have been studying how molluscs accomplish this (Webb et al., 1991).

This area is rapidly growing into an industry and has already produced a journal called 'Biomimetics' with articles such as: 'Metallized nanotubules derived from bacteria'. As Derek Birchall of ICI recently wrote: 'Biology does not waste energy manipulating materials and structures that have no function and it eliminates those that do not function adequately and economically. The structures that we observe work and their form and microstructure has been developed and refined over millions of years. ...... it is well, then, to look for fresh insights to biology at the wisdom encapsulated in the materials it uses' (Birchall, 1989). This is a re- statement of the theory of evolution by natural selection in the words of a materials engineer.

The second example is the uses being found for spiders, their silk and their venoms. Some kinds of spider produce silk that snares large, fast-flying prey with minimal damage to the projectile or the web. The combined properties of low weight, small diameter, extreme strength and the ability to absorb large amounts of kinetic energy are widely sought after (Vollrath & Edmonds, 1989). One recent application is bullet-proof vests filled with spider silk. There are currently several research labs figuring out, with considerable imagination, how to obtain huge quantities of spider silk for industrial applications (Helton, 1990; Beard, 1992).

The special properties of some spider venoms that paralyse rather than kill appear to have great potential for microsurgery where nerves and their associated muscles must be kept inert for short periods (Walker, 1991). In another area, the genes that produce venoms are being sought for incorporation into viruses - especially baculoviruses - that attack insects. The viruses would then be applied to crops as pesticide sprays. A similar role is being found for the venoms of scorpions and predatory mites (Tomalski & Miller, 1991; Stewart et al., 1991). Notwithstanding that these novel methods of pest control have some serious ecological and epidemiological problems, not least the lack of specificity, they illustrate the subtly and versatility with which the evolutionary paradigm can be put to use.

In each of the spider examples, there is a basic evolutionary question: in what circumstances, or under which conditions of natural selection, would the desired kinds of silk or venom have evolved?

Evolutionary biology has identified a variety of potential or proven invertebrate biological resources: cryoprotectants from collembola and mites (Lee et al., 1993), nematodes and mites for biocontrol (Gerson & Smiley, 1990), sea slugs and nematodes for brain research (Amit, 1990; Chalfie and Wolinsky, 1990), termiticides from ants (Augereau, 1988), ant- repellants from ants and wasps (Jeanne et al. 1983; Anderson et al., 1991), leeches for anti- coagulants (Sawyer, 1986; Biopharm ^{R}) bird-repellants from Hemiptera (Mason et al., 1991), biological control of weeds (McEvoy et al., 1991) and animal pests (Tumlinson et al., 1993), adhesives from Onychophora (N. Tait, pers. comm.) and annelids (Gaill et al. 1991) and a variety of invertebrates for biological monitoring (Rosenberg & Resh, 1993; Peakall, 1992) and biological control (DeBach & Rosen, 1991).

These examples include a significant proportion of the invertebrate groups, especially the largest: the Nematoda, Insecta, Chelicerata, Annelida, Crustacea, Mollusca and Echinodermata. As a consequence it is reasonable to assert that they are biological resources and that biologists have a well-established and rigorous discipline to find them and put them to use.

INVERTEBRATE CONSERVATION

These examples not only demonstrate the importance of the conservation of invertebrates, but the conservation of invertebrate species. This is because most of the adaptations sought are the products of individual genomes that code for precisely that life-history, behaviour, product, bioactive compound or interaction that is required. The biological control of *Salvinia* in Australia is a superb example. One species of weevil was a failure while another, almost identical weevil was a roaring success (Room, 1990).

In all of these cases the basic resources are genes that come in packets called species. Those who advocate that the conservation of biodiversity is only possible by the conservation of entire landscapes, ecosystems and communities are correct. However, it would be wise not to lose sight of one crucial reason for this — the resource potential of the genes, the species, they harbour. The mere maintenance of ecosystem function will not achieve this.

Finally, writers have agonised over the reasons for conserving species, knowing that many, perhaps most people, are persuaded only by utilitarian arguments rather than moral, ecological or ethical ones (Ehrenfeld, 1988; Randall, 1991). I share this concern but have come to the conclusion that like it or not the world will remain a market place and that, at the very least, the instrumentalist argument should be fully explored.

To be sure, only a small fraction of species are ever likely to be useful in a direct sense (Lawton, 1991), but exploration of biodiversity using the evolutionary paradigm is revealing previously unimagined applications almost daily. This raises the question: have the utilitarian arguments been seriously underestimated, especially for the invertebrates? When it comes to arguing for the conservation of invertebrates the ethical arguments still have first place and arguments for the role of invertebrates in ecosystem function may well come second. However, the utilitarian arguments for the discovery of new invertebrate resources have been poorly explored so far. Many of the examples presented here are serious in the sense that they are already commercial ventures. In other words, invertebrates already have a proven track record as biological resources in the strict commercial sense. They will become even more important as evolutionary ecology is applied to a widening range of human problems. The following quotation below remains as true today is it was 300 years ago: 'All we have yet discovered is but a trifle in comparison with what lies hid in the great treasury of nature.' Antoni van Leewenhoek (1680).

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